

The University of Chicago

THE IRON REQUIREMENT OF
CHILDREN OF THE EARLY
SCHOOL AGE

A DISSERTATION SUBMITTED TO THE
FACULTY OF THE DIVISION OF THE
BIOLOGICAL SCIENCES IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF HOME ECONOMICS AND
HOUSEHOLD ADMINISTRATION

1941

By

FRANCES A. JOHNSTON

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THE IRON REQUIREMENT OF CHILDREN OF THE EARLY SCHOOL AGE

FRANCES A. JOHNSTON

*Department of Home Economics and Household Administration, and
Department of Pediatrics, The University of Chicago, Illinois*

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Although a number of studies have been made on the iron requirement of infants and preschool children, little is known concerning the requirement of the child of school age. It is the purpose of this study to make a contribution toward filling in this gap.

The method which has been used previously to determine the iron requirement has been that of the balance study. This method is a suitable one for finding the requirement of adults because the object is to find the lowest level at which the intake and outgo exactly balance. It is not necessarily applicable in the case of children, where the purpose has been to find an intake giving a large or even a maximum retention. It has been assumed that any excess beyond that needed to replace catabolic losses, and to furnish iron for growth as well as for a reasonable storage, would be excreted: that is, a child would not retain more iron than he needed. Of recent years experimental work has been done which indicates that this assumption was false.

Evidence that excess iron is not excreted was furnished by McCance and Widdowson ('38) who found that intravenous injections of iron in subjects on a constant iron intake resulted in practically no increase in fecal iron, and also by Hahn et al. ('39) who injected radio active iron in dogs and found that practically all the injected iron was retained, even though the dogs were so well stocked with iron that there was obviously no need for retention.

If excess iron is not excreted, large amounts will accumulate on high intakes. Such has been found to be the case by Hutchison ('37) who reported that when children were given large amounts of iron orally, all had large retentions as shown by balance experiments. The retention of one child in only 3.5 months was 3.5 gm., which is more than he could possibly have needed. Adults, too, have been shown to retain correspondingly large amounts on high iron intakes.

Since excess iron is not excreted, retentions may be much greater than the amount needed and there seems to be no way to tell how large retention should be. This being the case, it is necessary to find some criterion other than the size of the retention on a given intake for determining the amount of iron needed. Because a large proportion of the iron in the body is found in the hemoglobin, and because this is probably one of the first iron-containing tissues to be depleted when there is a deficiency, it would seem that a good hemoglobin level could be taken as an indication of an adequate iron supply. If so, the procedure would be to find the lowest level of iron intake that will produce and maintain a good hemoglobin level.

EXPERIMENTAL

The general plan. Subjects were selected who had been living for several years in an institution where the diet was fairly uniform, in order that their hemoglobin levels could be considered a product of that diet. Their hemoglobin levels were determined and iron analyses were made on their diets. They were then matched in groups of three and given graded amounts of iron. After the iron supplementation had been continued for 7 months, hemoglobin levels were again determined and the data examined to find the lowest intake that gave good hemoglobin levels.

The subjects. This study was carried out at Mooseheart, an institution whose standards of nutrition and physical care are high. Twelve boys and nine girls, from the ages 8 to 11 years were selected as subjects. As a group, their nutritional condition rated higher than average. None of them had had

iron therapy or had suffered severe or chronic blood loss. All but one had been living on the diet of the institution for 2 years or more. It seemed, therefore, that their hemoglobins would be the product of that diet.

The diet. The diet was a good one containing all the foods customarily advised for children. Calculations made on the diets of the subjects showed that all were up to or above the daily allowances recommended by the Committee on Food and Nutrition of the National Research Council ('41) for every dietary essential. Probably, therefore, the diet furnished all the dietary factors which affect hemoglobin.

The blood study. Capillary blood was taken from the ear lobe. Hemoglobin determinations were made in duplicate by the method of Evelyn ('36) using the Evelyn Photoelectric Colorimeter. The red cells were counted from two pipettes of blood on a Bright-line Improved Neubauer Haemocytometer. The blood samples were taken during the time the dietary study was being made, on two different days, a week or two apart, always at the same time of day for the same child. The children were kept sitting quietly for at least 45 minutes before each test, and were kept as free as possible from excitement.

The individual hemoglobin values ranged from 13.8 to 11.6 gm. per 100 ml. of blood (table 1). The mean hemoglobin for all twenty-one children was 12.9 gm. The red cell counts ranged from 3,810,000 to 4,730,000 cells per cubic millimeter with a mean of 4,160,000 (table 2). There was no significant difference between the two sexes; the mean for the boys was 12.7 gm. of hemoglobin and 4,200,000 red blood cells per cubic millimeter and for the girls was 13 gm. and 4,120,000 cells. Since the analytical method was not accurate to more than 0.5 gm., all those hemoglobins falling between 12.5 and 14.5 gm. were within experimental error of the zone 13 to 14 gm., an area which is generally accepted as high normal.¹ Sixteen

¹ Evidence that the value 13-14 gm. of hemoglobin is a normal level for children in excellent health was obtained by an examination of the hemoglobin values of the state winners of the 4-H Club health contests. This information was made available by the Elizabeth McCormick Memorial Fund.

of the children fell in this zone; three fell in the range of 12 to 12.5 gm., which would still be considered normal; two fell in the range of 11 to 12 gm. which might be called low normal; and none even approached an anemic level which is usually considered as 10 gm. or below.

The iron intake of the subjects. The dietary study extended over a period of 2 weeks. A period of this length was used because it had been found by previous studies, made in this laboratory (McClelland, '31), that this is the shortest period

TABLE 1

The relationship of the average daily iron intake to the original hemoglobin level.

SUBJECT AND SEX	AGE	HEIGHT	WEIGHT	HEMO- GLOBIN	TOTAL IRON	IRON PER KILOGRAM
	<i>yr.-mo.</i>	<i>cm.</i>	<i>kg.</i>	<i>gm.</i>	<i>mg.</i>	<i>mg.</i>
T.R.—M	9- 5	137.3	29.4	13.8	14.6	0.50
C.W.—F	10-10	143.4	33.4	13.6	11.4	0.35
B.H.—M	9- 0	131.8	32.2	13.5	14.8	0.46
B.C.—M	10- 0	137.0	32.6	13.4	12.5	0.38
D.S.—F	10- 4	140.3	33.4	13.3	11.6	0.35
G.Ho.—F	10- 9	141.5	37.7	13.3	11.7	0.31
B.Co.—F	10- 1	135.0	31.6	13.2	11.9	0.38
R.C.—F	9- 2	136.8	31.2	13.1	10.8	0.35
H.S.—F	10- 5	135.6	39.0	13.1	12.0	0.31
J.J.—M	8- 8	130.4	28.6	13.0	12.8	0.45
B.W.—F	9- 4	142.3	31.7	13.0	11.7	0.37
A.H.—F	11- 3	147.5	43.3	13.0	13.0	0.30
G.H.—M	8- 3	130.9	28.2	12.9	12.6	0.45
G.B.—M	9- 2	128.8	26.2	12.9	13.1	0.50
R.J.—M	9- 8	134.9	33.4	12.7	14.6	0.44
A.Z.—M	9- 4	137.2	32.2	12.5	11.3	0.35
L.P.—M	9-11	139.0	35.8	12.4	14.8	0.41
C.R.—M	9- 3	134.9	32.4	12.2	15.1	0.46
E.D.—M	9- 7	130.8	28.2	12.0 ¹	11.9	0.42
A.P.—F	9- 7	135.9	31.5	11.7	11.1	0.35
R.H.—M	10- 1	126.8	25.5	11.6	11.2	0.44
Ave. M and F	9- 9	136.1	32.3	12.9	12.6	0.40
Ave. M	9- 4	133.3	30.4	12.7	13.3	0.44
Ave. F	10- 2	139.8	34.7	13.0	11.7	0.34
H.S. ²	10- 5	135.6	39.0	13.1	11.4	0.29

¹ Later rose to 13-14 area.

² For 12-week period.

that will furnish an accurate sample of a subject's customary intake. The food each child ate was weighed on Hanson spring scales to an accuracy of 1 gm. The subjects drank from thermos bottles filled with measured amounts of tap

TABLE 2

The effect of iron administration for 7 months on the red cell counts and hemoglobin values.

		HEMOGLOBIN			RED CELLS		
		Grams per 100 ml.			Millions per c.m.m.		
		Spring	Fall	Change	Spring	Fall	Change
0 mg. added iron							
Boys	T.R.	13.8	14.3	+0.5	4.73	4.34	-0.39
	B.C.	13.4	14.1	+0.7	3.97	4.27	+0.30
	J.J.	13.0	13.8	+0.8	4.41	3.97	-0.44
	C.R.	12.2	12.0	-0.2	4.11	3.85	-0.26
Girls	B.Co.	13.2	13.0	-0.2	3.84	3.86	+0.02
	H.S.	13.1	14.2	+1.1	4.51	4.30	-0.21
	A.H.	13.0	13.0	0.0	4.10	3.75	-0.35
Average		13.1	13.5	+0.4	4.24	4.05	-0.19
2 mg. added iron							
Boys	B.H.	13.5	12.8	-0.7	4.45	4.51	+0.06
	G.H.	12.9	12.5	-0.4	3.98	3.86	-0.12
	E.D.	12.0	12.7	+0.7	3.97	4.23	+0.26
	L.P.	12.4	sick		4.40	sick	
Girls	G.Ho.	13.3	13.7	+0.4	4.18	4.18	0.00
	R.C.	13.1	13.4	+0.3	4.46	4.10	-0.36
	B.W.	13.0	13.2	+0.2	3.91	3.79	-0.12
Average		12.9	13.0	+0.1	4.19	4.14	-0.05
4 mg. added iron							
Boys	G.B.	12.9	12.3	-0.6	4.44	4.06	-0.38
	R.J.	12.7	13.3	+0.6	3.81	4.22	+0.41
	A.Z.	12.5	12.9	+0.4	4.15	4.14	-0.01
	R.H.	11.6	11.7	+0.1	3.96	3.78	-0.16
Girls	C.W.	13.6	13.2	-0.4	4.04	3.96	-0.08
	D.S.	13.3	13.1	-0.2	4.00	3.95	-0.05
	A.P.	11.7	12.3	+0.6	4.01	3.86	-0.15
Average		12.6	12.7	+0.1	4.06	4.00	-0.06
Average of all subjects		12.9	13.1	+0.2	4.16	4.05	-0.10

water. Weekly composites were made of 1/10 aliquots of the food weighed on trip scales to an accuracy of 1/10 gm., and 1/10 aliquots of water were added.

The composites were digested with concentrated hydrochloric acid on a steam bath. Samples taken from the digests were wet-ashed. Iron was determined on an aliquot of the ash solution by a modification of Stugart's thiocyanate method ('31), with the use of an Evelyn Photoelectric Colorimeter. All containers were rinsed with dilute hydrochloric acid and triple-distilled water, and all possible precautions taken to avoid contamination.

The results of the iron analyses are shown in table 1. It will be noted that the total intakes ranged from 10.8 to 15.1 mg. with a mean of 12.6 mg. The mode, however, lay in the group below the mean, nine out of twenty-one children having intakes between 11.0 and 11.9 mg. and one being only slightly lower (10.8). In general the intakes of the boys were higher than those of the girls; the respective mean intakes were 13.3 and 11.7 mg. or 0.44 and 0.34 mg. per kilogram. The higher intake of the boys is interesting in view of the fact that they had neither a higher hemoglobin nor a higher cell count than the girls.

That the diet during the 2 weeks of the study was typical not only of the present diet but also of the one that had produced the hemoglobin level of the subjects, was borne out by three lines of evidence.

1. A chemical analysis of the diet of one of the girls for 10 additional weeks from April 6th to June 15th showed daily mean intakes of 10.5, 11.4, 10.9, 11.5, 11.2, 10.8, 11.2, 11.4, 12.5, 11.6 mg. with a mean for all 12 weeks of 11.4 mg. This was very near 11.7 mg., the mean for all the girls of the study.

2. Calculations were made from the dietitian's records of food supplied to each of the three cottages in which the subjects lived, for each month of the year, 1939-1940, including the months in which the 2-week samples were taken. The values for the 2 months in which the study was made were

14.5 and 15.5 mg. per day, values which were similar to those for the other months, and to the yearly average of 15 mg.

3. It happened, also, that records were available from a dietary study made in the same institution in 1932. They were compared with the calculated values found in the present study (1940) to determine whether the iron content of the diet had been the same for the last few years. Both of these computations were made from weights taken at the time the food was served on the plates. The mean for the 1932 group was 12.1 mg. and for the 1940 group, 12.6 mg.

Thus all three lines of evidence showed that the 2-week sample was surprisingly typical of the diet on which the children had been living.

The iron supplementation. The object in giving the iron supplements was to see whether the hemoglobin levels of any of the children would rise. A rise would indicate that the amount of iron originally in the diets was too small. The size of the supplement needed to bring about a rise would furnish information for estimating the minimum requirement.

The children having about the same hemoglobin values and red cell counts and approximately the same weight were arranged in groups of threes. One from each group was given 4 mg. of iron in addition to that in the diet, one 2 mg., and the third child none. These amounts were such that the total iron intakes per day would not be greater than could be obtained from foods. The supplement was given as the iron salt, ferric pyrophosphate. It was mixed with the milk in order to parallel the physical relationship of the iron in foods as nearly as possible. This salt was selected because it had been found by other workers to give good absorption when mixed with milk. This iron therapy was continued for 7 months because the amount of additional iron was so small that a long period was necessary to allow for a slow accumulation of new hemoglobin. At the end of this period, hemoglobin and red cells were again determined by the same methods and under the same conditions as at the beginning.

The results, as given in table 2, show that no significant change occurred in the blood picture, not even in the case of the subjects whose hemoglobin values were a little low. The hemoglobin would have had to rise as much as 1 gm. to be certain of a real change. In only one case was there as great a change as 1 gm. and that child was one of the controls who had no additional iron. The average for the whole group gave no indication of a tendency of the hemoglobin to rise. Only small and insignificant changes were found in the red cell counts. The supplementation, therefore, yielded no information as to the lowest iron intake needed for the formation of a good hemoglobin level but did show that the children were getting at least enough iron before the supplement was added.

The lowest intakes found to be sufficient. Since the real object of the whole study was to find the lowest level of iron intake that would support a good hemoglobin level, the data should be examined with this in mind. The subjects have been arranged in the order of the descending amounts of hemoglobin in table 1. The lowest amount of iron in the diet of a subject with a hemoglobin level of 12 gm. or higher was 10.8 mg. per day. This was but one case. That of six subjects averaged 11.4 mg. per day, which was exactly the average daily intake of the one subject who was studied for 10 additional weeks. It seemed justifiable, therefore, to consider this amount sufficient to cover the needs of children of this age.

Since, however, the children varied in age and size, the per kilogram values may have more significance. If all the subjects with a hemoglobin level of 12 gm. or more are considered, it will be observed that three of the children had good hemoglobin levels on approximately 0.30 mg. per kilogram. Since one of these was the child kept on the experiment for 12 weeks, and the only one showing a significant increase in hemoglobin level, it may be that 0.30 mg. per kilogram is sufficient. However, since these three children were all above the standard weight for children of their age, and would thus have a relatively high total intake on a low per kilogram intake, it might

not be wise to apply this figure to all children. The ten subjects with the lowest intakes were receiving 0.30 to 0.40 mg. per kilogram. Only two of these were boys. However, if two boys could build a good hemoglobin level on this amount, the rest could probably have done so. The mid-value of 0.35 mg. per kilogram would therefore appear to be an adequate allowance. If this value is applied to all the children of the study, it gives an average total iron of 11.3 mg. This is almost identical with the average total (11.4 mg.) of the six subjects with the lowest intakes and good hemoglobin values.

DISCUSSION

Intakes of 11.4 mg. or 0.35 mg. per kilogram were apparently sufficient for the formation of a good hemoglobin level, but were they actually larger than necessary? This question cannot be answered with certainty until accurate studies have been made at lower intakes than these. Nevertheless it is possible to find some information on this point. The view that a lower intake would have sufficed is supported by the study of Davidson et al. ('33) who made a study among large groups of people from the poorer classes in Scotland. Calculations of the iron content of the diets were made from the foods entering the homes. Intakes of iron as low as 5 to 6 mg. "per man" (no doubt less per child) were found among families in which there was no anemia. In a study of 3000 individuals, Davidson and Fullerton ('38), also, found considerable anemia among very young children and women but little among men and children of the early school age. Since these people came from the poorer classes, the diets of the children undoubtedly contained less iron than that found in the diets of the subjects of the present study. The findings of Ross and Summerfeldt ('36) are to the contrary. They made a study on children 5 to 14 years of age living in an orphanage. The average hemoglobin for the group was low (10.2 gm.) although the diet, as calculated, contained 11 mg. of iron. Since the diets of their subjects were not as good as those of the present study and since supplementation with vitamins

B₁ and B₂ improved the hemoglobin of their subjects, it seemed likely that their diets may have been deficient in factors other than iron necessary for hemoglobin formation. Such experimental evidence as exists, therefore, points to the probability that the iron requirement as found by this study is higher than it needs to be.

It may be justifiable to try to get some idea of the minimum requirement by calculations such as those which have been published by Heath and Patek ('37). They estimated the amount of iron which would have to be retained each year in order to furnish enough for a normal increase in tissue and blood from birth to the end of the period of growth (table 3).

TABLE 3

Estimates of the iron requirements of boys¹ from 2 to 11 years based on the retention figures of Heath and Patek.²

AGE	WEIGHT	RETENTION PER YEAR	INTAKE PER YEAR	INTAKE SMOOTHED	INTAKE PER DAY	INTAKE PER KILOGRAM
<i>yr.</i>	<i>kg.</i>	<i>mg.</i>	<i>mg.</i>	<i>mg.</i>	<i>mg.</i>	<i>mg.</i>
2	13.4	80	800	850	2.3	0.17
3	15.3	92	920	920	2.5	0.16
4	17.3	98	980	980	2.7	0.15
5	19.6	79	790	1050	2.8	0.14
6	22.2	80	800	1120	3.1	0.14
7	24.6	70	700	1180	3.2	0.13
8	27.9	72	720	1250	3.4	0.12
9	30.9	152	1520	1320	3.6	0.12
10	34.5	130	1300	1390	3.8	0.11
11	37.6	137	1370	1450	4.0	0.11

¹ Retentions for girls are approximately the same.

² Heath, C. W., and A. J. Patek, Jr. 1937. The anemia of iron deficiency. *Medicine*, vol. 16, p. 279.

In order to find the size of the intake necessary to obtain a given retention, reference has been made to the percentage of retention found in balance experiments on children by the method of iron analysis used in this study.

Ascham ('35) and Oldham et al. ('37) found retentions of about 10%. Porter ('41) found retentions of about 20%. With the use of the polarographic method of analysis, Macy ('41) reported retentions of approximately 10%. Since it

is safest to use the percentage which would require the highest intake, a retention of 10% has been assumed for purposes of calculation. The required retentions as computed by Heath and Patek have then been multiplied by 10 to find the intake necessary to produce them and the values have been smoothed by inspection. By this method of calculation, a child of 10 would need a total of 3.8 mg. per day or 0.11 mg. per kilogram (see table 3). The intakes of all the subjects of the present study were much higher than this.

However, children of these ages need not only enough iron for maintenance and growth but also enough to allow the storage of iron in the liver and other storage depots. If the values given in table 3 are increased by 100% on the assumption that most of the stores must be accumulated in these years, the intake would be 7.6 mg. or 0.22 mg. per kilogram at 10 years. Thus even with allowances of 90% for loss in absorption and 100% for storage, the calculated iron requirement is still below the intakes found in the present study. It is true that figures such as these calculated ones, backed by no experimental work, cannot be used with much confidence but they do perhaps give some indication that the children of this experiment were getting even more iron than they needed for maintenance, growth and storage.

It may be of interest to compare the intakes of 0.35 mg. per kilogram found sufficient for the children of this study with those previously found for preschool children by means of the balance experiment. The requirements suggested have ranged from 0.60 mg. per kilogram (Rose et al., '30; Daniels and Wright, '34; Ascham, '35) to 0.48 mg. (Leichsenring and Flor, '32). However, since Porter ('41) has recently reported good retentions on intakes averaging 0.31 mg. per kilogram, it may be that the upper value of 0.60 mg., which has generally been accepted, is higher than it needs to be.

SUMMARY

The purpose of this study was to find the iron requirement of children of the early school age. This was to be accom-

plished by finding the lowest iron intake which would support a good hemoglobin level.

Hemoglobin determinations were made on twenty-one children 8 to 11 years of age. Of these, nineteen had hemoglobin levels of 12-14 gm., the range considered normal.

The iron intakes were found by making a chemical analysis of the diet of each child over a 2-week period. An examination of the intakes indicated that good hemoglobin levels could be maintained on 11.4 mg. per day or 0.35 mg. per kilogram when the rest of the diet was adequate.

That a higher intake was not needed was shown by the fact that the hemoglobins of children given 2 or 4 mg. of iron daily over a 7-month period did not rise. It is possible, also, that lower intakes, had they been tried, might have been found to serve just as well.

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